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A UK PERSPECTIVE ON THE UNIFORM ENGINE TEST PROGRAMME

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June 1989

Procurement Executive, Ministry of Defence

Farnborough, Hants

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SUMMARY

The Uniform Engine Test Programme (UETP) involved the testing of two Pratt and Whitney J57 engines at seven Government-owned test sites in Europe and North America, four of them having altitude test facilities. This collaborative programme was organised by a working group of the Advisory Group for Aerospace Research and Development (AGARD) and provided actual test data as a basis for comparison of methods of testing and analysis amongst the international aero engine testing community. An overview of the UETP is given in this Paper, together with a brief review of the test results. Nozzle coefficients are used as a basis for comparing gross thrust and airflow measurements and differences in some of the other performance parameters are compared with the predicted precision and bias errors. Great Britain.

Presented at the 1989 European Propulsion Forum on "Modern Techniques and Developments in engine and component testing" held in Bath, England from 19-21 April 1989, organised by the Royal Aeronautical Society and Co-sponsored by L'Association Aeronautique et Astronautique de France and Deutsche Gesellschaft fuer Luft-und-Raumfahrt eV.

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1 INTRODUCTION

Altitude test facilities, which permit aero engines to be tested at simulated altitude and forward speed, were first built during the mid-1960s in countries wanting a major stake in the aero engine business. The amount of instrumentation fitted to engines under test, methods of testing and techniques of data analysis developed along generally similar lines at all these test sites, with major advances being made following the introduction of powerful computer-controlled data gathering and analysis systems in the mid 1970s.

Cooperation and exchange of information amongst the altitude testing community was informal at first, but as engine development programmes came to involve more than one manufacturer or nation and engines developed in one country were used in other countries airframes, so the desire for an international perspective on altitude testing grew. The Advisory Group for Aerospace Research and Development (AGARD), which promotes exchange of scientific and technical information amongst the NATO community, offered the organisational structure under which a collaborative programme could be started. Subsequently, AGARD Working Group 15 was set up and the uniform engine test programme (UETP) was proposed in 1979 as a practical step in obtaining actual test data as a basis for comparison of methods of testing and analysis.

The programme involved testing the same two engines at each of the participating test sites, and, through the generosity of the US Government, two Pratt and Whitney J57 engines were provided for this purpose. Seven Government owned test sites took part in the test programme, although only four of these had altitude test facilities, the other three having ground-level test beds. Details are given of the participants in the order of testing in Table 1.

Altitude test Cell No.3 at the Royal Aerospace Establishment, Pyestock was provided by the UK Ministry of Defence Procurement Executive for this programme, one of five altitude test cells on the site and the one usually allocated for military aero engine testing. A description of Cell 3 and the test envelope that can be covered is given in Appendix 1 for the benefit of those outside the immediate altitude testing fraternity. RAE(P) did not test an engine in a ground-level test bed and were primarily interested in the altitude test results, so only this aspect of the UETP is considered in this overview paper.

A general test plan (Ref 1) was drawn up to ensure that, as far as possible, all test facilities set up the same range of altitude conditions, measured the same parameters and presented the performance results in a standard format. The test conditions in terms of inlet pressure, temperature and ram ratio are given in Table 2. Special precautions were taken to identify any deterioration in performance by taking measurements at specific conditions at the beginning and completion of the test series at each site. In addition, the engines were tested at one facility both at the start and finish of the complete series.

The testing programme took longer than originally anticipated to complete because of national priorities on other programmes delaying access to test cells at some sites and the inevitable delays in transporting two engines across Europe and the USA. Data from the other testers were not made available until a facility's own tests were completed, at which point they became involved in the further analysis and comparison of all the test data. Specific assignments were given to each member of the Working Group, and RAE(P) was asked to look closely at thrust and airflow measurements.

A subject which attracted a great deal of attention from all members, especially in the latter stages of the Working Group's deliberations was measurement uncertainty. This must be kept to a very low level in order to sustain confidence in the results of altitude testing. Special precautions were introduced many years ago at RAE(P) to ensure that the random errors associated with calibration of measuring instruments and collection of data were kept very low. However, the bias error, which does not change with time, is extremely difficult to determine and the only practical way of finding the likely bias error at any test site is by taking measurements at several facilities and comparing results. Thus it became evident that the UETP offered a unique opportunity to determine bias errors. To support this investigation, bias error limits were separately predicted by each test site using a method which synthesised the uncertainty of a measurement from its component parts, and this too was compared with the measured levels of uncertainty.

The AGARD Working Group formally finished meeting in 1988 when a comprehensive final report prepared by the Group was ready for publication (Ref 2). A separate report on measurement uncertainty was prepared by a specialist sub-group (Ref 3), but the present short paper can only address a few of the topics dealt with in the main reports. It is mainly written to give an overview of the UETP, as seen by one of the participants, and to display evidence of the accurate performance measurements that can be taken in altitude test facilities. Assessment procedures used at RAE(P) for this purpose, such as nozzle coefficients for thrust and airflow analysis and uncertainty methodology for classifying and interpreting measurement errors, are described.

2 REVIEW OF TEST RESULTS

A considerable quantity of test data were provided by each test site so there was a need to condense these into an easily understandable format. Performance parameters of greatest interest were plotted on graphs and included in the test report. These were grouped into sets of four per page, of which Fig 1 is a typical example. Altogether, 18 pages of results in this format were included in Ref 1.

To give some idea of how closely the results were in agreement, the spread of values at a mid-thrust point on each graph as well as the percentage of test points falling within a 2% band were determined. A summary of this analysis is given in the table below.

Coordinates	% spread at mid-thrust [without CEPr]	% test points within 2% band [without CEPr]
NL v NH	0.4 to 0.8 [0.04 to 0.6]	99
T7/T2 v P7/P2	0.6 to 2.0 [0.3 to 1.3]	98
WA1 v NL	1.3 to 3.6 [1.3 to 2.9]	88
WF v NH	3.8 to 5.5 [1.0 to 3.0]	63 (85)
FN v P7/P2	3.4 to 5.4 [0.3 to 3.3]	69 (92)
SFC v FN	0.9 to 2.4 [0.9 to 2.4]	89

where:-

NL,NH - high and low pressure rotor speeds
T7/T2 - exhaust/inlet temperature ratio
P7/P2 - exhaust/inlet pressure ratio
WA1 - inlet air flow
WF - fuel flow
FN - net thrust
SFC - specific fuel consumption

Values are quoted with and without CEPr data included as this test site produced results for WF v NH and FN v P7/P2 which were noticeably different from the other participants, possibly due in part to not allowing sufficient time for the engine to stabilise before taking a set of measurements. With this exception, the overall spread of results is generally better than 3% with at least 85% of the data lying

within a 2% band. There was very little deterioration of the engine and a study by AEDC concluded that engine performance remained essentially constant from beginning to end of the UETP. Thus the performance measurements taken in the four altitude facilities were generally in good agreement.

3 NOZZLE COEFFICIENTS

3.1 Method of analysis

A convergent nozzle of fixed geometry supplied at entry with an airflow having a uniform pressure distribution yields a unique relationship when thrust coefficient CG8 is plotted against nozzle pressure ratio.

$$CG8 = \frac{\text{Measured gross thrust}}{\text{Isentropic gross thrust for the same nozzle area and pressure ratio}}$$

This nozzle characteristic is typically shaped as in Figure 2a. The coefficient rises with increase in pressure ratio until the nozzle becomes choked, when it flattens off and remains constant thereafter. In the case of a gas turbine engine, tested at different altitude conditions and hence having a range of nozzle pressure ratios, this method of thrust analysis should present a good collapse of the data around the nozzle characteristic. If the results are plotted whilst the test is in progress, a means of identifying measurement errors is provided.

The actual results for thrust coefficient plotted against nozzle pressure ratio obtained at one test facility often show some variation with altitude conditions due to engine-related effects and test facility measurement errors, see Figure 2b. The engine-related effects come from a variety of sources. At a given nozzle pressure ratio a change in altitude and forward speed usually means a change in engine power setting. The power setting, in turn, influences the profile of the airflow at nozzle entry through changes to swirl angles and pressure distribution. With a limited pressure sampling system these effects are inadequately accounted for and lead to changes in thrust coefficient. Also, as altitude is increased, Reynolds number is lowered and the boundary layers on the gas generator turbo machinery are affected, giving rise to changes to the inlet total pressure profile at entry to the nozzle.

In the UETP, where thrust coefficients were compared between test facilities for the same engine, further differences can be identified. These can also be divided into two categories, those due to different test cell geometries and those due to measurement errors between test sites, ie bias errors. Examples of test cell geometry effects include, nozzle to exhaust diffuser gap and relative diameter, inlet duct geometry, etc.

These inter-facility thrust coefficient differences are pictorially depicted in Figure 2c. Whilst this approach will not reveal reasons for the differences between test facilities, it will nevertheless identify their existence. Abnormal or unexpectedly large differences can then be investigated in greater detail by the test centres themselves in an attempt to identify a specific reason. The actual range of thrust coefficients obtained by RAE(P), around which an envelope has been drawn, is shown in Fig 3a.

This method, which has been outlined for thrust coefficient is equally applicable to the discharge coefficient CD8 which is mainly a function of airflow.

$$CD8 = \frac{\text{Measured airflow}}{\text{Isentropic airflow for the geometric area at the same pressure ratio}}$$

In both cases a consistent and good spatial measurement of nozzle entry total pressure (P7) is needed. The UETP engines were therefore instrumented with total pressure and temperature rakes in the jet pipe in order to obtain good average measurements. Nevertheless, the initial analysis of thrust and airflow using coefficients revealed abnormally large differences, as is seen by the comparison of CG8 in Fig 3b. This result could not be reconciled with other measurements, in particular thrust against engine low rotor speed. An analysis of the measurement of the nozzle total pressure at the different sites led to doubts about the consistency of this parameter. It appeared that as the jet pipe and nozzle were removed for transporting after each test series and re-assembled on arrival at the next site, this might have led to a possible circumferential misalignment of the rakes relative to the engine. Since the engine itself contained turbine support vanes, etc it led to the possibility of differences in total pressure measurement at nozzle entry due to geometry differences. NASA carried out specific tests to show that circumferential placement of the rakes did indeed influence the calculation of nozzle total pressure.

A secondary factor affecting nozzle total pressure derivation was the integrity of individual probes on the rake. Some probes or pressure sensors failed during the course of the test series and therefore the later test sites used fewer measurement to obtain nozzle total pressure.

Fortunately, the engine jet pipe contained a static pressure tapping and this proved to be a rugged measurement. All test sites were able to record this measurement, a single sample, without failure and NASA showed in their special tests that it was insensitive to jet pipe circumferential location. This measurement therefore, was used in the UETP thrust and airflow analysis to thermodynamically derive nozzle total pressure using the jet pipe area and a gamma value of 1.35. The new calculated nozzle total pressure was, in turn, used to re-calculate the ideal gross thrust and airflow in order to establish the nozzle coefficients. The thrust and

airflow coefficients were replotted in Figures 4a and 4b, and as can be seen by comparing Figures 3b and 4a, a significant reduction in the spread of results was obtained.

3.2 Gross thrust comparison

Figure 4a shows the results for gross thrust coefficient for the four altitude test facilities. A close examination of this figure shows that CEPr generally gives a thrust coefficient higher than the other three facilities across the complete pressure ratio range, some 1 to 1.5 percent higher. The exception to this is the CEPr results at a test condition 9, a high altitude condition, where thrust coefficients are considerably lower than all their other test conditions. Although this is a low Reynolds number condition, and might be expected to yield lower coefficients, this result is somewhat worse than expected. These results have been separated from the other CEPr conditions in the figure.

The RAE(P) and NASA results agree well at lower pressure ratio and show a 1/2 percent difference at higher levels. The AEDC results show a generally wider spread than RAE(P) or NASA and a closer examination revealed a trend with engine inlet pressure, a lower coefficient for a lower pressure. The spread amounted to approximately 2.0 percent whereas the NASA and RAE(P) spread were 0.5 to 0.75 percent. This result was not repeated with the other engine tested at AEDC which yielded a narrower spread of 0.5 to 0.75, percent, comparable with the RAE(P) and NASA results.

3.3 Airflow comparison

The results for the nozzle discharge coefficient are shown in Figure 4b for the four altitude test facilities after similar treatment to that described earlier. An examination of the figure shows that the AEDC and RAE(P) results agree in spread but the level of the RAE(P) results is slightly lower than AEDC by approximately 0.25 percent. The NASA and CEPr results are both above the AEDC coefficients, NASA approximately 1 percent and CEPr 2 to 2.5 percent above the AEDC level. The CEPr high altitude results for airflow are, like the thrust results, below the levels for all the other test conditions by as much as 3 percent, suggesting some altitude-related effect on their measurement system. A more comprehensive treatment of these subjects is given in references 4 and 5.

4 UNCERTAINTY METHODOLOGY

Measurement uncertainty has already been mentioned as one of the factors responsible for differences in test results between the various test facilities and a lot of attention was paid to quantifying its effect in the final phase of the UETP. Measurement errors can be classified as precision or bias according to the way they affect the test result and the task of explaining these distinctions and the approach used in the UETP is aided by reference to Figure 5.

The SFC versus net thrust relationship is an example of a typical performance result and Figure 1 gives the results at four test conditions for each of the four altitude test facilities. As explained in section 2 this is but one of a series of test results given in this format published in the UETP Final Report. One of these curves is considered in isolation in Figure 5.

4.1 Precision

Precision or random errors are related to the well-known scatter observed in most experimental results. Fig 5a shows a least squares curve (solid line) fitted to the measured test points (circles). The scatter of points is assumed to follow a Gaussian distribution. The residual standard deviation (RSD) of individual test points from the curve can be calculated using statistical methods whilst a test is in progress. This calculated figure can be checked against a predeclared value which is acceptable to the test facility and its customers. At RAE(P) the acceptable RSD is typically 0.25%, corresponding to a scatter band of ±2 x RSD, ie ± 0.5%. Occasional points outside this band are generally deleted, but if points fall consistently outside the band an investigation is instigated.

In theory, the random uncertainty of a performance curve gets smaller as the number of test points increases. Hence, if time and expense were no object, this uncertainty could be made progressively small, simply by taking a lot of test points. An alternative way of controlling the test is to begin with only a small number of points (say four) and then add points, one at a time, until the desired low uncertainty is reached. This is the most cost-effective method. However, for the UETP it was agreed that all facilities would take the same number, ie 9 pairs or 18 points in all. This was more than sufficient to reduce the effects of precision errors to negligible amounts (except, possibly, for WF v NH, which is a very steep curve) as the following table shows:-

EFFECT OF PRECISION ERRORS IN RAE TESTS

Performance graph	RSD [%] at Test Condition			Uncertainty [%] at Test Condition		
	3	6	9	3	6	9
SFC v FN	0.06	0.20	0.28	0.09	0.09	0.19
FN v P7/P2	0.06	0.03	0.17	0.09	0.04	0.19
WF v NH	0.20	0.17	0.29	0.28	0.21	0.35
WA v NL	0.07	0.14	0.17	0.11	0.18	0.19

4.2 Bias

Bias error is not so straightforward either to identify or eliminate. Turning to Figure 5b, it can be seen that another curve has been drawn alongside the test result curve which represents the true curve, although its exact position is not known. The bias error, β, is the difference between the fitted curve and the true curve. With just one facility's results, the bias error cannot be observed, but with four measured curves from different test facilities it is not unreasonable to assume that the true curve lies close to the mean of the four measured curves. Thus the values of β can be estimated for the SFC versus thrust curves of Figure 1 and this has been done for the four test conditions at the mid-curve value. Values of β are shown plotted on Figure 6a, using the same symbols as Figure 1 for each test site.

As this is the very first time an opportunity has arisen to identify bias errors in altitude test facilities, further corroborative evidence is clearly highly desirable. Another approach to identifying bias uncertainty was therefore employed in the UETP. This was based on predictions of the way measurement uncertainty builds up on each individual parameter which contributes to the calculation of the more complex parameters such as SFC. Transducers connected to the engine tappings are generally calibrated against a bench standard, which in turn is calibrated against a transfer standard traceable to the national standard of each country. Each link in the calibration chain removes all the gross errors but leaves a small measurement uncertainty which can be predicted from a knowledge of the calibration histories on that equipment together with judgement based on long experience in the field. In addition, there are uncertainties associated with installation of the tappings which introduce space and time averaging uncertainty plus other physical effects such as hole geometry and probe interference. Accounting for some of these effects tend to be a more subjective art than an exactly calculable science. A complex parameter such as SFC is a function of thrust and fuel flow which in turn are functions of airflow, pressure and temperature measurements, so the prediction of bias error for SFC is a lengthy and complicated process. However, each test site performed such predictions for an agreed list of parameters, including SFC, at three test conditions (Ref 6). Thus for each test facility the predicted bias limits (±B) can be compared with the measured bias errors β. The bias limits give the range within which the bias error should lie with a high level of confidence. The bias limits for each test site have been plotted as vertical bars on top of the individual values of bias error on Figure 6a.

It is noteworthy that in this example nearly all the bias errors are within the bias limits. In statistical terms, the observed β values should lie well within the predicted ±B limits, so it seems that some of the latter may have been a little underestimated (which is a natural tendency). However, the prediction process is so complicated that to obtain near-agreement with the observed errors must be regarded as a remarkable achievement. To show that this is not an isolated fortunate result,

a comparison of bias errors and bias limits for airflow versus LP shaft speed is given in Figure 6b, giving a similarly satisfactory result.

Returning now to the comparisons of nozzle thrust and airflow coefficients, the predicted bias limits for these parameters, determined by RAE(P) for their facility at four altitude conditions, have been drawn to scale at the top of Figure 4 to enable the measured differences in CG8 and CD8 to be compared with a typical set of bias limits. This enables a judgement to be made on whether the differences in the measured values are large enough to warrant further detailed investigation. It can be seen from the figures that, with a few exceptions already described, the observed differences in the coefficients are generally within the predicted bias limits. It can therefore be concluded that, only the largest differences justify further investigation and that the altitude test facilities gave acceptable agreement for both gross thrust and airflow measurements.

5 CONCLUDING REMARKS

The Uniform Engine Test Programme provided a unique opportunity for aero engine test facilities in Europe and North America to evaluate their test procedures and methods of analysis by testing the same engines over an agreed range of operating conditions. The performance results obtained at altitude conditions were generally in good agreement, although there were differences in some parameters which justify further analysis by the test sites themselves. The use of nozzle coefficients, which can be calculated whilst a test is in progress, was demonstrated to be an effective means of identifying differences in airflow and thrust measurements, although not in itself sufficient to isolate the reasons for any differences.
Each test site benefited in different ways from participating in the UETP, not least from observing how other test sites approached the testing, through participating in working group discussions on methods of analysis and in writing the final report. RAE(P) gained particular benefit from establishing the bias error of performance measurements against the other test facilities and finding this to be less than 1.5%. The UETP provided the first opportunity for bias errors to be identified in this way and because of the considerable resources it absorbed is not likely to be repeated for many years to come, if ever. It is therefore highly satisfactory to have found that the bias errors fell within the predicted bias limits, giving added confidence in the use of the prediction methodology for different test cells and engine types in the future. The effects of precision errors were confirmed as being much smaller than bias, ie not greater than 0.3%, a result which RAE(P) believe to be highly creditable and a good reflection on the test procedures used in altitude test facilities..

The UETP involved the Pratt & Whitney J57 two-spool turbojet which is not representative of more advanced military turbofan engines now under development. Turbofan engines are likely to be more sensitive to installation effects such as exhaust nozzle to diffuser spacing, inlet profile and Reynolds Number. Test facilities may need to pay greater attention to these factors in any joint test

programmes in the future. With hindsight, tests on a high-quality open air test stand at the beginning of the programme would have provided a datum against which both altitude and sea-level test beds could be compared. Also, the test envelope for the altitude facilities would ideally have included conditions at a higher ram ratio, corresponding to operation at higher Mach numbers. Nevertheless, to have concluded the UETP is a remarkable achievement and the AGARD final report will warrant close study for some time to come.

Appendix I

DESCRIPTION OF CELL 3 AT RAE PYESTOCK

1 GENERAL DESCRIPTION

Cell 3 is a ground-based altitude facility used for testing military combat aircraft engines over a wide range of simulated forward speed and altitude. It is one of five test cells at the Royal Aerospace Establishment, Pyestock, which can be used to test a variety of engines and rigs. A typical engine installation in Cell 3 is shown in diagrammatic form in Figure 7. The engine is mounted on a support stand which is suspended on oil-filled bearings so that it can float in the axial direction. Any movement is restrained by a load measurement device positioned below the support stand. Air is supplied by plant compressors through the air mains into a plenum chamber from where it is drawn through the airmeter into the inlet ducting and hence into the engine. A slip joint near the engine intake provides a controlled radial gap which allows freedom of movement between the engine intake and the fixed inlet ducting. Gauzes may be placed in the inlet duct to produce any desired pressure distortion pattern representative of that produced by an aircraft intake at the engine face.

The pressure and temperature of the air at inlet to the engine can be controlled within close limits to simulate the required altitude and forward speed. Low temperature air is produced by a cold air turbine which delivers air at a temperature of -70°C which is then mixed with warmer air to produce the required temperature. Cell pressure is lowered to the desired altitude value using exhauster compressors which extract air from the test cell together with the exhaust gases of the engine under test. As the exhaust gases of a reheated military engine may be as high as 2000°C these have to be progressively cooled down to 50°C in the exit diffuser section and gas cooler using water-cooled tubes before entry into the exhauster compressors. Provision is made to burn off any unburnt fuel in the cell diffuser pipe using inhibition torches. Flame traps minimise the risk of explosions of any remaining unburnt fuel in the air mains. The test cell can be run continuously with an engine in full reheat without any restrictions on the length of test.

The test cell is fully equipped with a computer-controlled comprehensive data gathering system which caters for both steady state and transient measurements. All of the steady state parameters can be read into computer memory in about 20 seconds, after which the complete steady state performance of the engine is calculated and displayed on a visual display unit for immediate interpretation by the test engineers. The computer also compares the data collected against that expected, identifying any measurements which appear to be outside specified limits. Transient measurements can also be obtained from a lesser number of parameters (up to 120 at

present but with room for expansion). Selected parameters may be displayec on another VDU shortly after a transient manoeuvre has been completed. Permanent records for subsequent analysis are also available.

2 TEST ENVELOPE

The test envelope in terms of Mach number versus altitude for a military combat powerplant is given in Figure 8. The engine may be operated at any point within this envelope at a thrust level between flight idle and maximum combat rating with reheat on. It should be noted that the cell altitude pressure cannot be lower than than that corresponding to 5000 ft, even though the inlet conditions can be accurately simulated. The plant and engine operating conditions can be held stable at any point to enable all of the steady state measurements to be obtained and analysed. The engine may also be accelerated and decelerated by throttle movement to enable the handling characteristics to be evaluated. Surge detection equipment can be used to automatically reduce fuel to the engine if compressor surge should be detected following rapid throttle movement. Changing from one point to another on the test envelope usually takes only a few minutes, but obviously this does not enable changes in flight conditions to be experienced in real time.

3 DATA HANDLING AND ANALYSIS

3.1 Steady state system

An engine to be tested is usually delivered to the test site with quick connect couplings which enable it to be readily linked to the test cell measurement system. Gas pressure transducers are situated in temperature controlled cabinets to maintain a stable calibration whilst liquid pressure transducers are located within the cell in an environmental enclosure. Thermocouples are linked to an electronic temperature reference unit. Parameters such as fuel flow and rotor speeds give frequency signals which are processed by one of the frequency input channels. Thrust is measured by a strain gauged load cell which has its own proprietary conditioning equipment.

3.2 Transient system

The transient systems pressure transducers are mounted as close to the pressure source as possible to provide fast response and are usually installed by the engine manufacturer. These, together with temperatures, fuel flows, thrust, etc are conditioned by a separate high-speed electronics unit at rates of up to 375 Hz for 120 channels of data. Lesser numbers of channels can be scanned at much faster rates, the highest being 48 KHz.

TABLE 1 UETP PARTICIPANTS IN ORDER OF TESTING

Facility title	Abbreviation	Altitude	Ground level
National Aeronautics and Space Administration	NASA	✓	
Arnold Engineering Development Center	AEDC	✓	
National Research Council of Canada	NRCC		✓
Centre d'Essais des Propulseurs	CEPr	✓	✓
Royal Aerospace Establishment (Pyestock)	RAE(P)	✓	
Turkish Air Force Supply and Maintenance Centre	TUAF		✓
Naval Air Propulsion Centre	NAPC		✓

TABLE 2 UETP TEST CONDITIONS

Test condition	Inlet total pressure kPa	Ram ratio	Inlet total temperature K
1	82.7	1.0	253
2	"	"	268
3	"	"	288
4	"	"	308
5	"	1.06	288
6	"	1.3	"
7	51.7	"	"
8	34.5	"	"
9	20.7	"	"
10	82.7	1.7	"

REFERENCES

No.		
1	J G Mitchell	Uniform Engine Test Programme: General Test Plan AGARD Working Group 15, June 1983
2	P F Ashwood et al	The Uniform Engine Test Programme Report of PEP Working Group 15. AGARD Advisory Report No.248 (1989).
3	J P K Vleghert	Measurement Uncertainty within the Uniform Engine Test Programme. AGARDograph 307 (1989).
4	A R Osborn	A Comparison of Gross Thrust Determination between UETP Test Facilities. RAE Technical Memorandum, P1101, February 1987
5	A R Osborn	A Comparison of Airflow Measurement between UETP Test Facilities. RAE Technical Memorandum P1118, September 1987
6	J C Ascough	Prediction Synthesis of Error Limits for J57 UETP Tests. RAE Technical Memorandum P1069, September 1985
7	J C Ascough G N Wort	Comparison of Bias Errors for UETP Facilities. RAE Technical Memorandum P1134, March 1988

ACKNOWLEDGEMENT

The authors are grateful to AGARD for permission to reproduce extracts from (Refs 2 and 3) in this Paper.

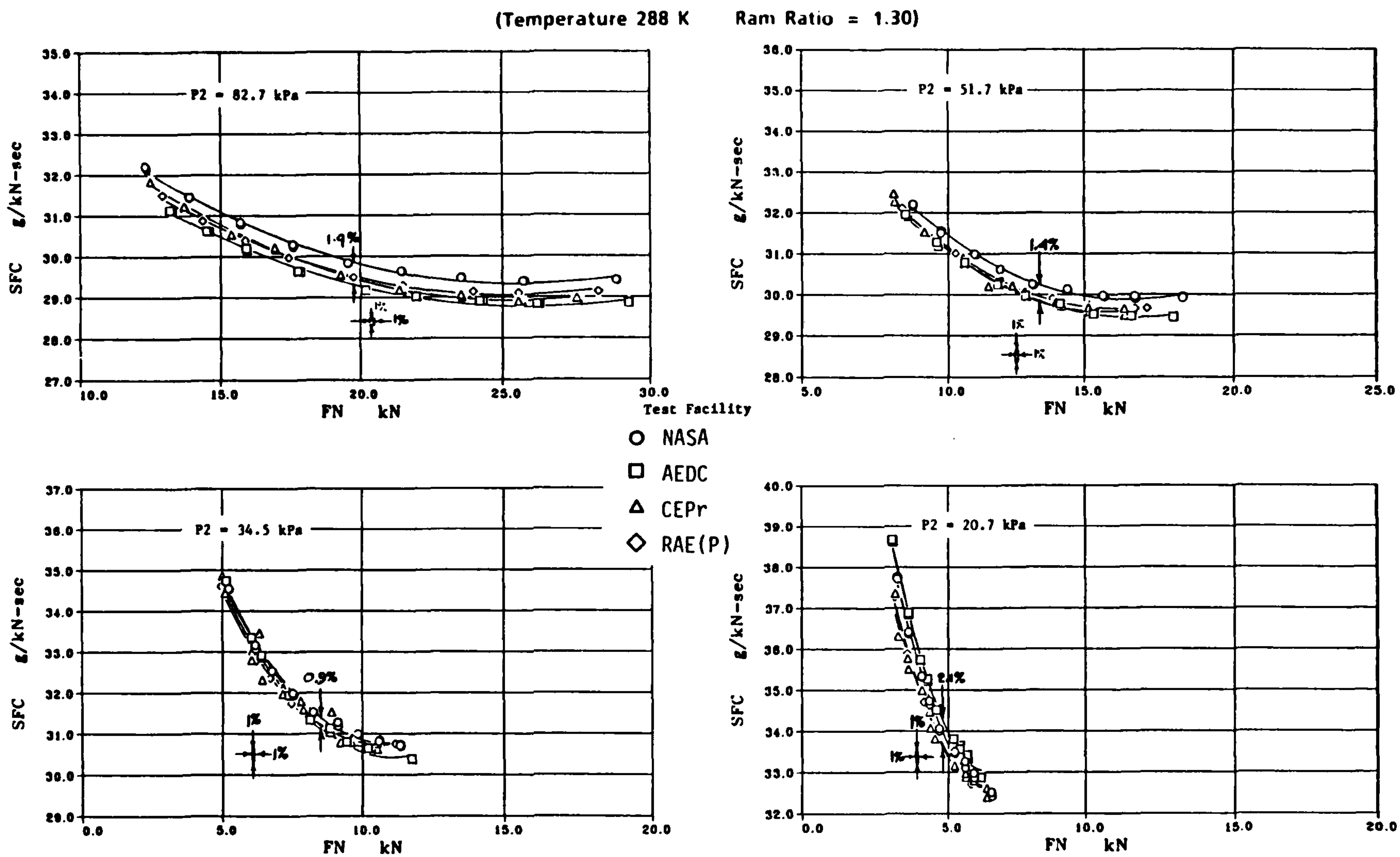

FIG 1 TYPICAL SET OF SFC v FN RESULTS

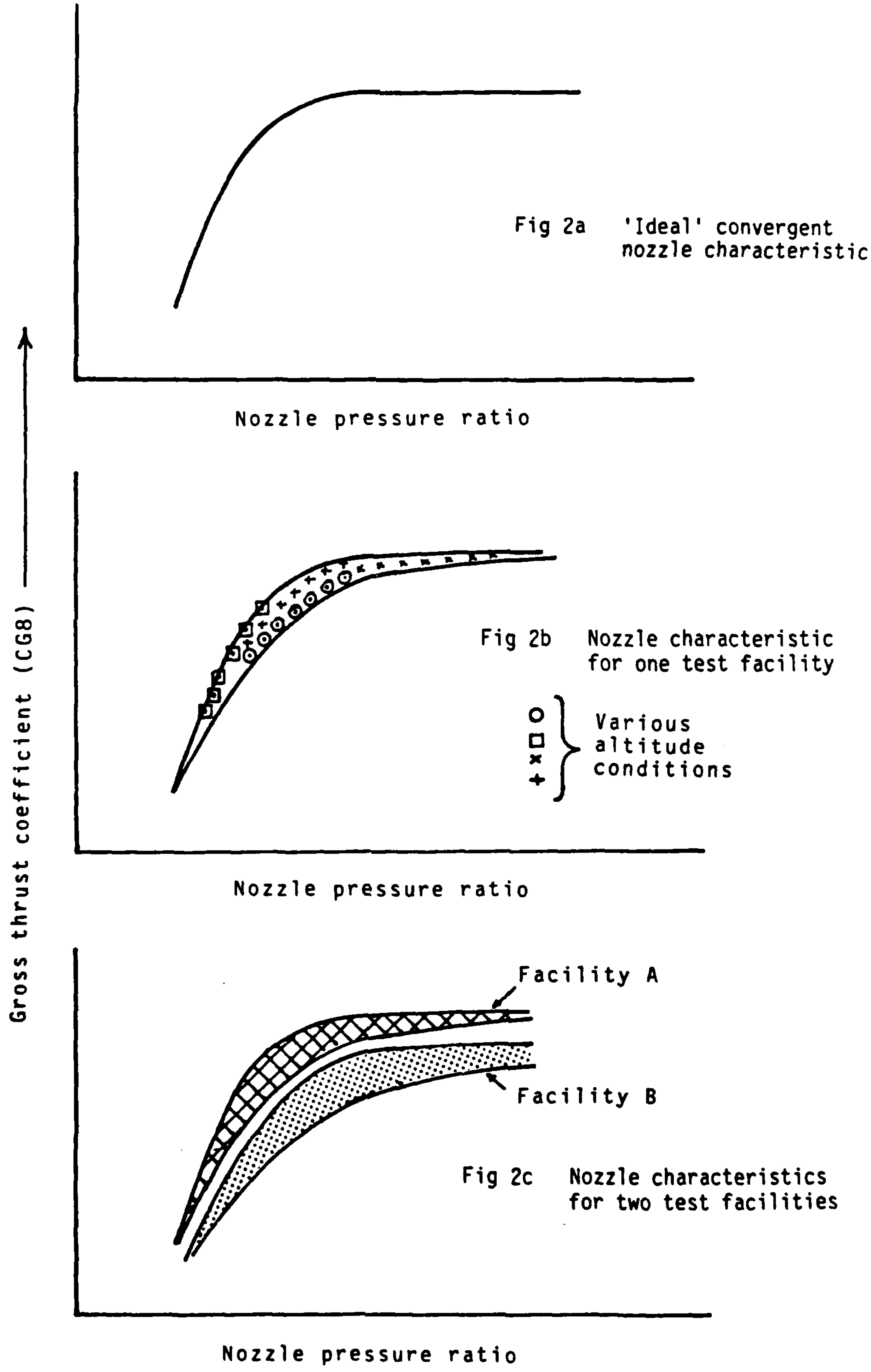

FIG 2 BASIS FOR GROSS THRUST COMPARISON

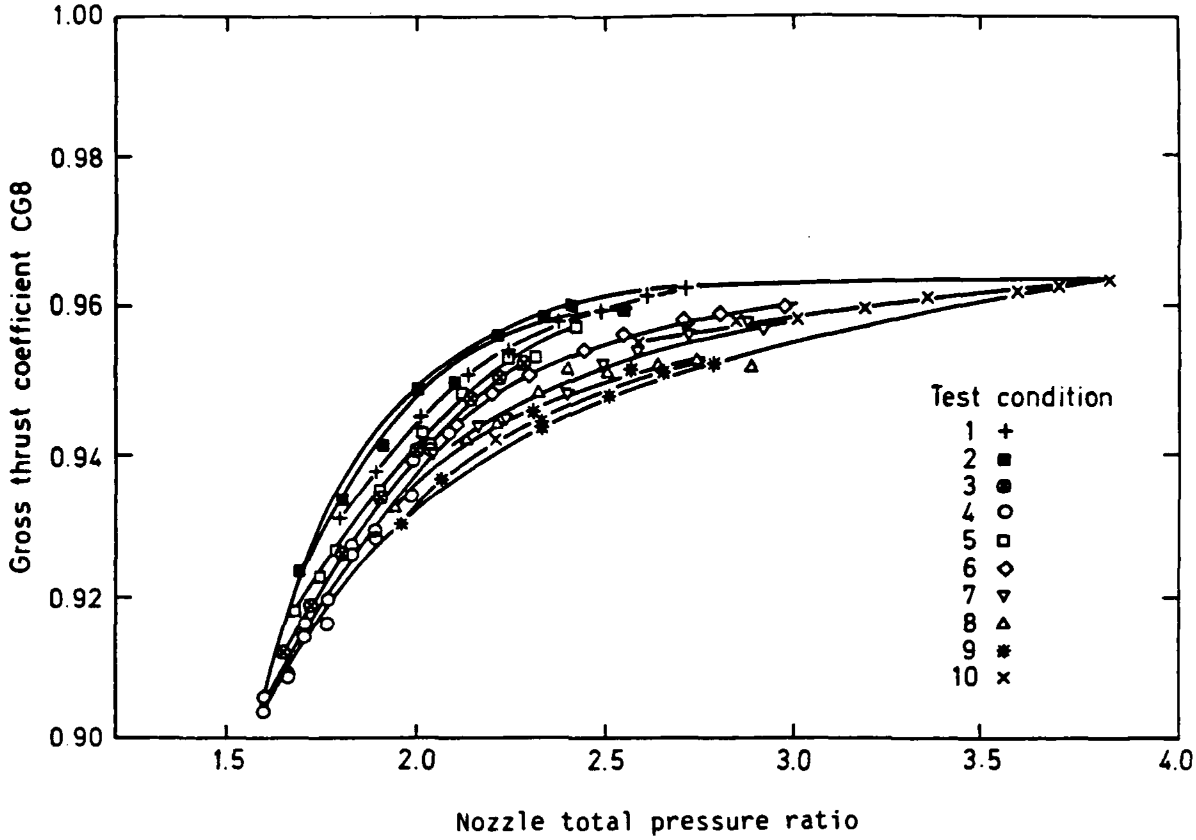

FIG 3A GROSS THRUST COEFFICIENT FOR RAE TEST RESULTS

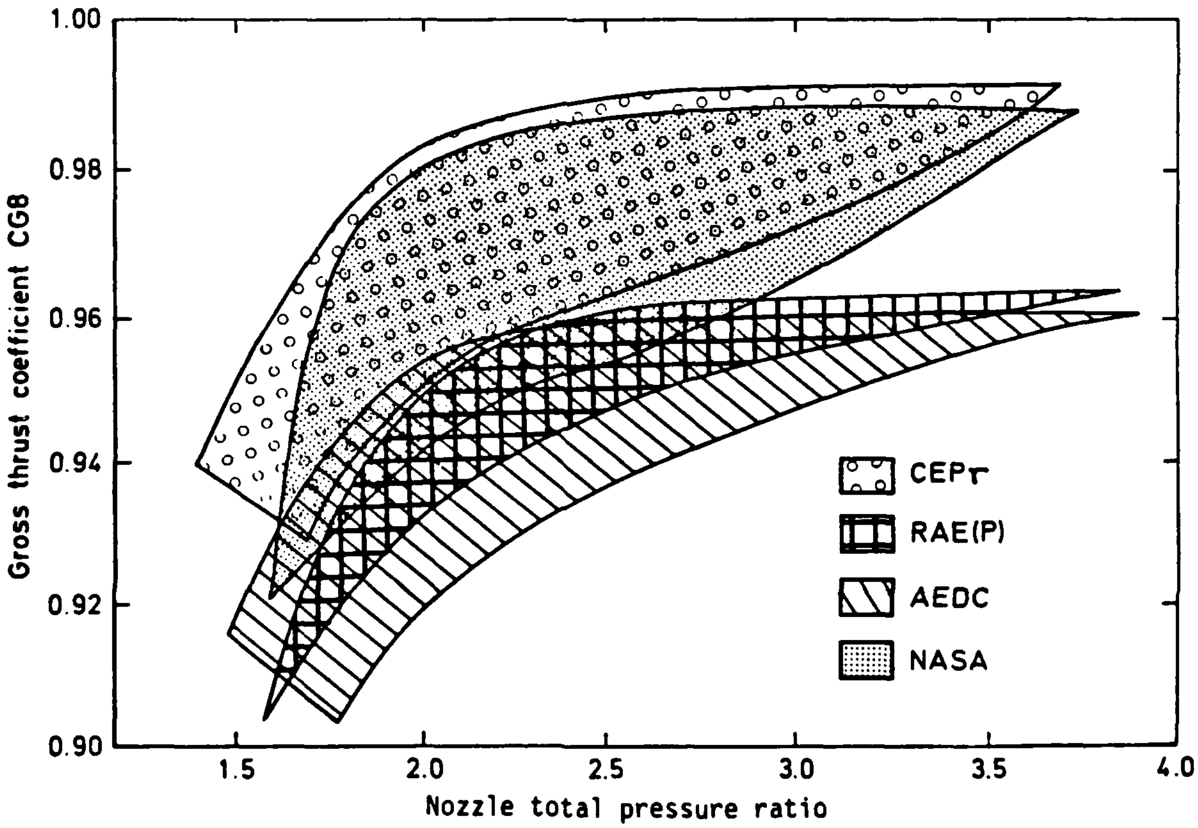

FIG 3B GROSS THRUST COEFFICIENT ENVELOPES FOR ALL ALTITUDE FACILITIES

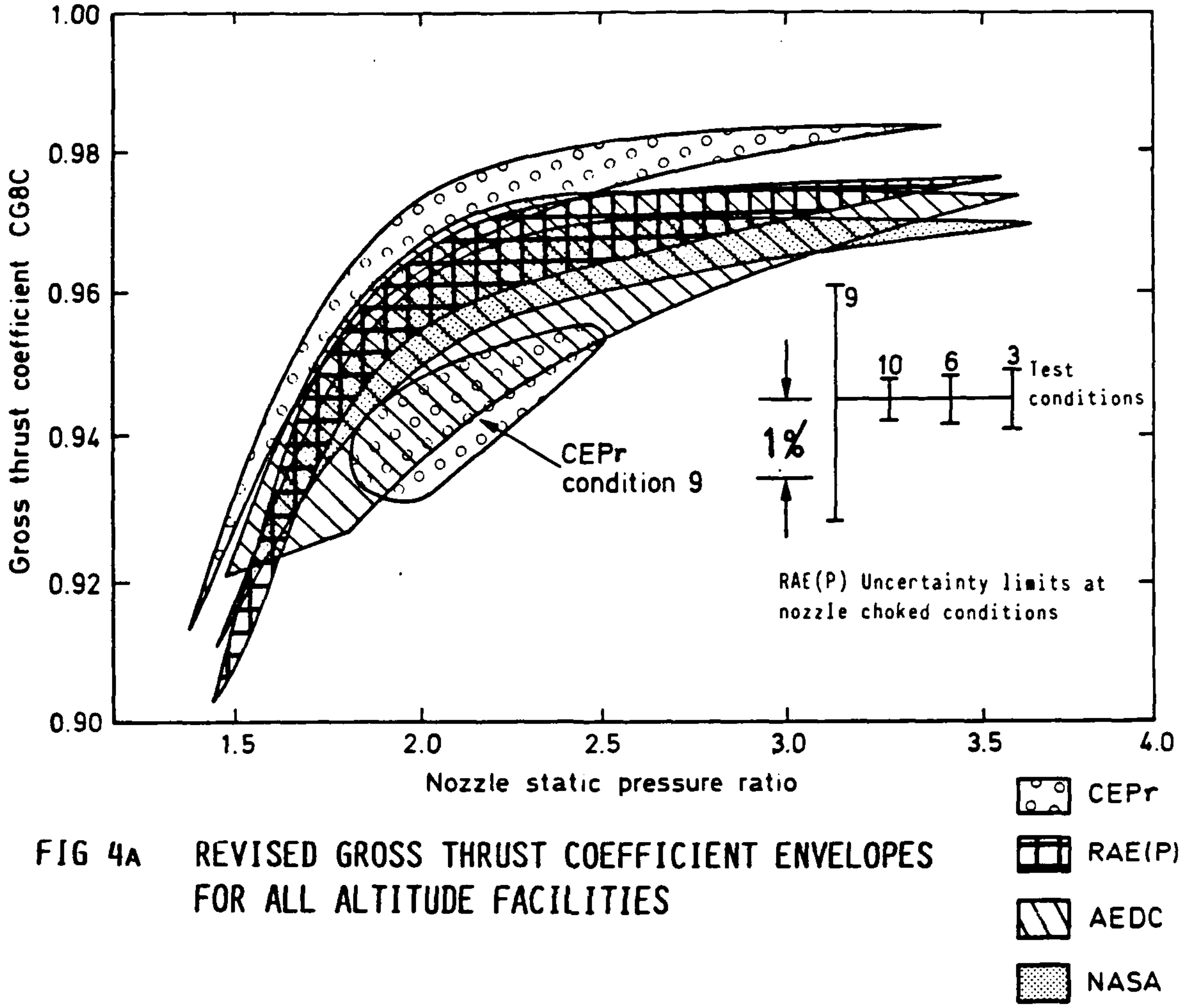

FIG 4A REVISED GROSS THRUST COEFFICIENT ENVELOPES FOR ALL ALTITUDE FACILITIES

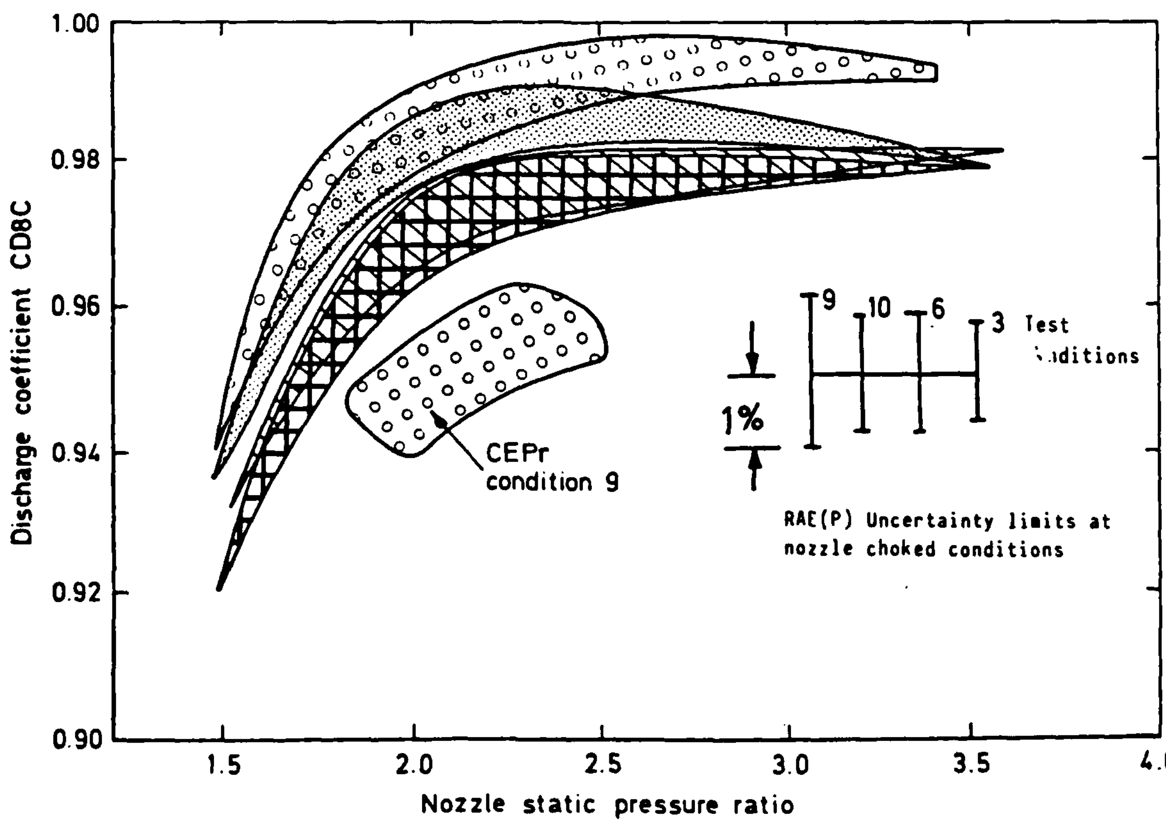

FIG 4B REVISED DISCHARGE COEFFICIENT ENVELOPES FOR ALL ALTITUDE FACILITIES

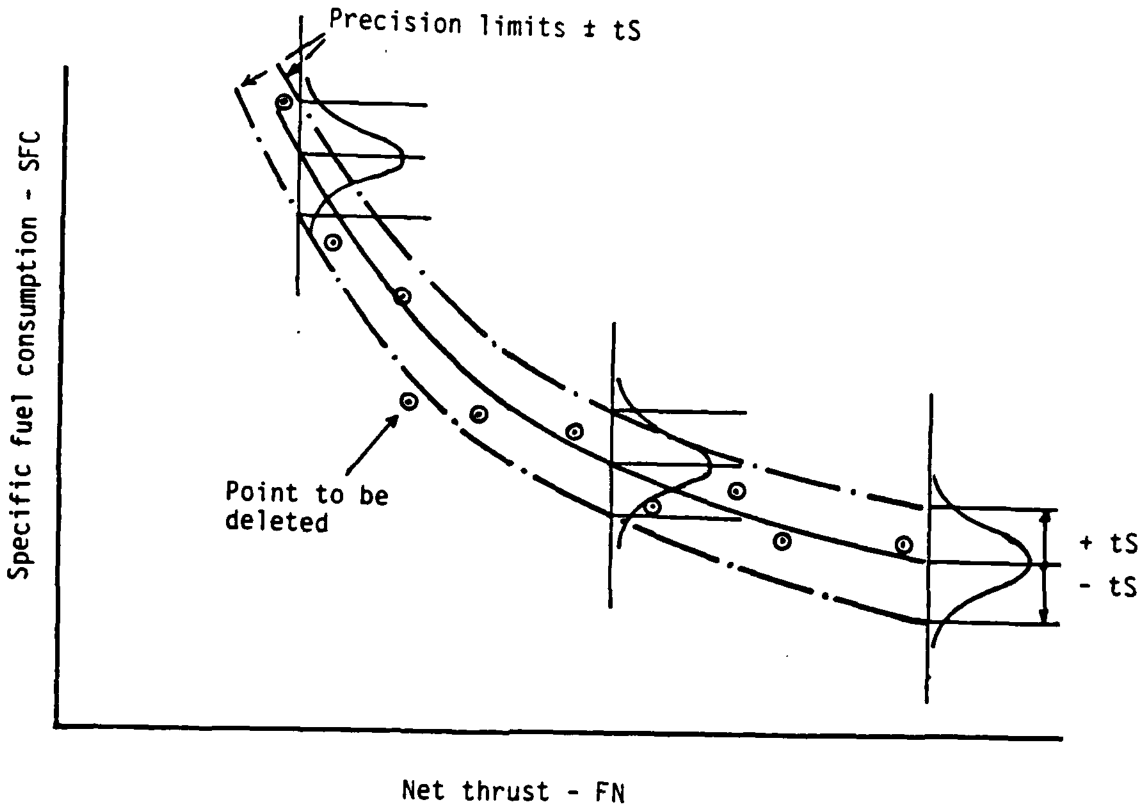

FIG 5A ILLUSTRATION OF PRECISION ERROR

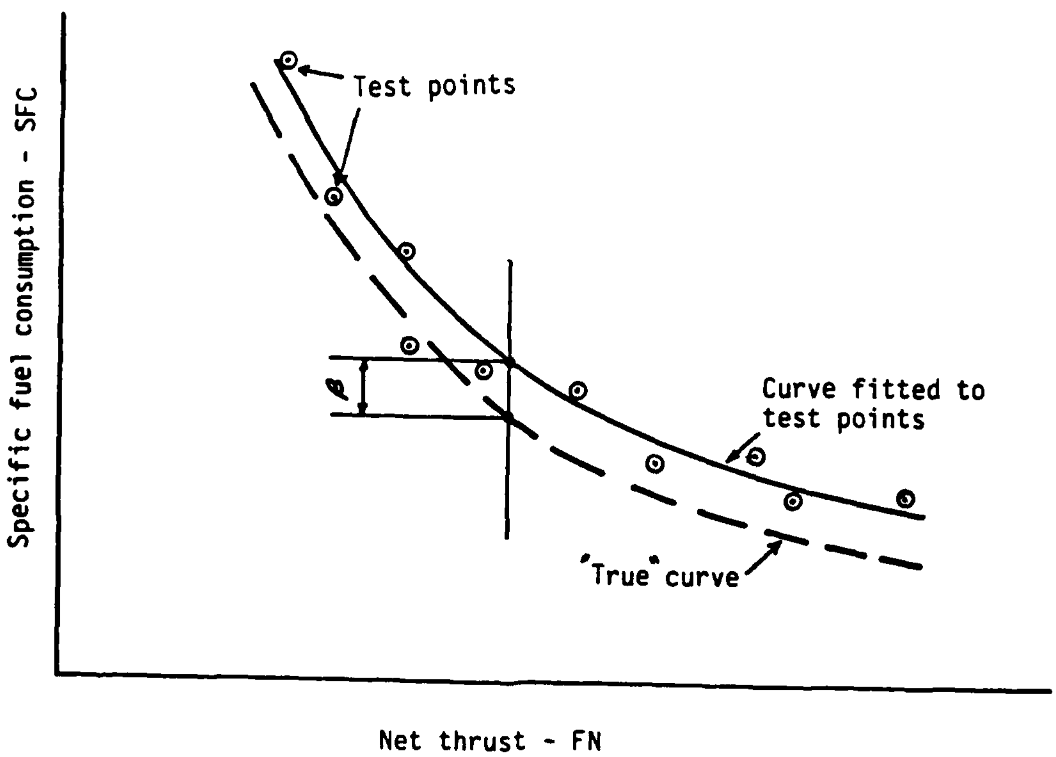

FIG 5B ILLUSTRATION OF BIAS ERROR

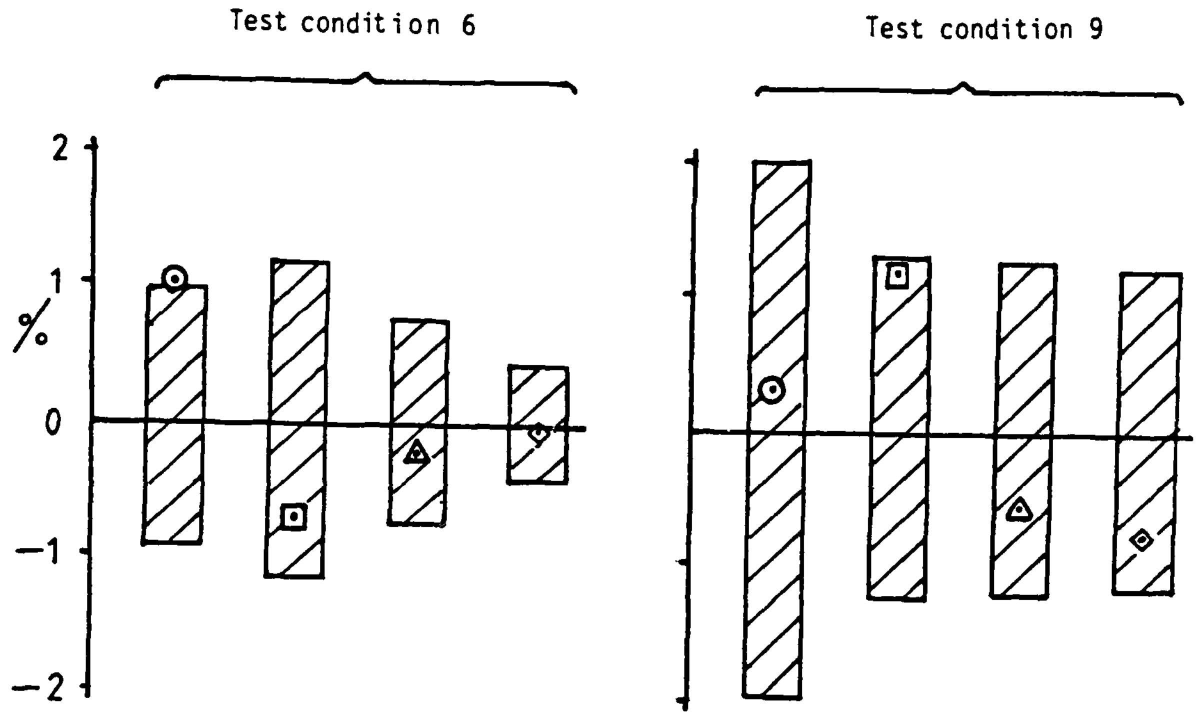

Fig 6a Results based on SFC V FN

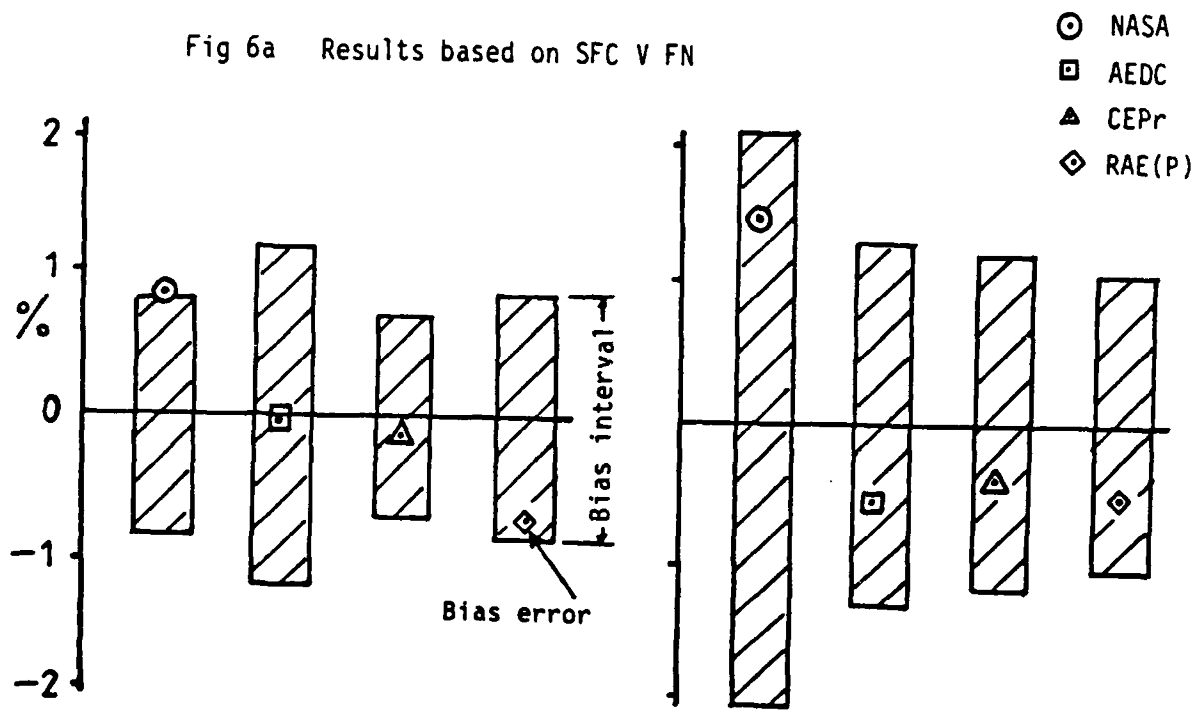

Fig 6b Results based on WA1 V NL

FIG 6 COMPARISON OF OBSERVED BIAS ERRORS WITH PREDICTED BIAS INTERVALS

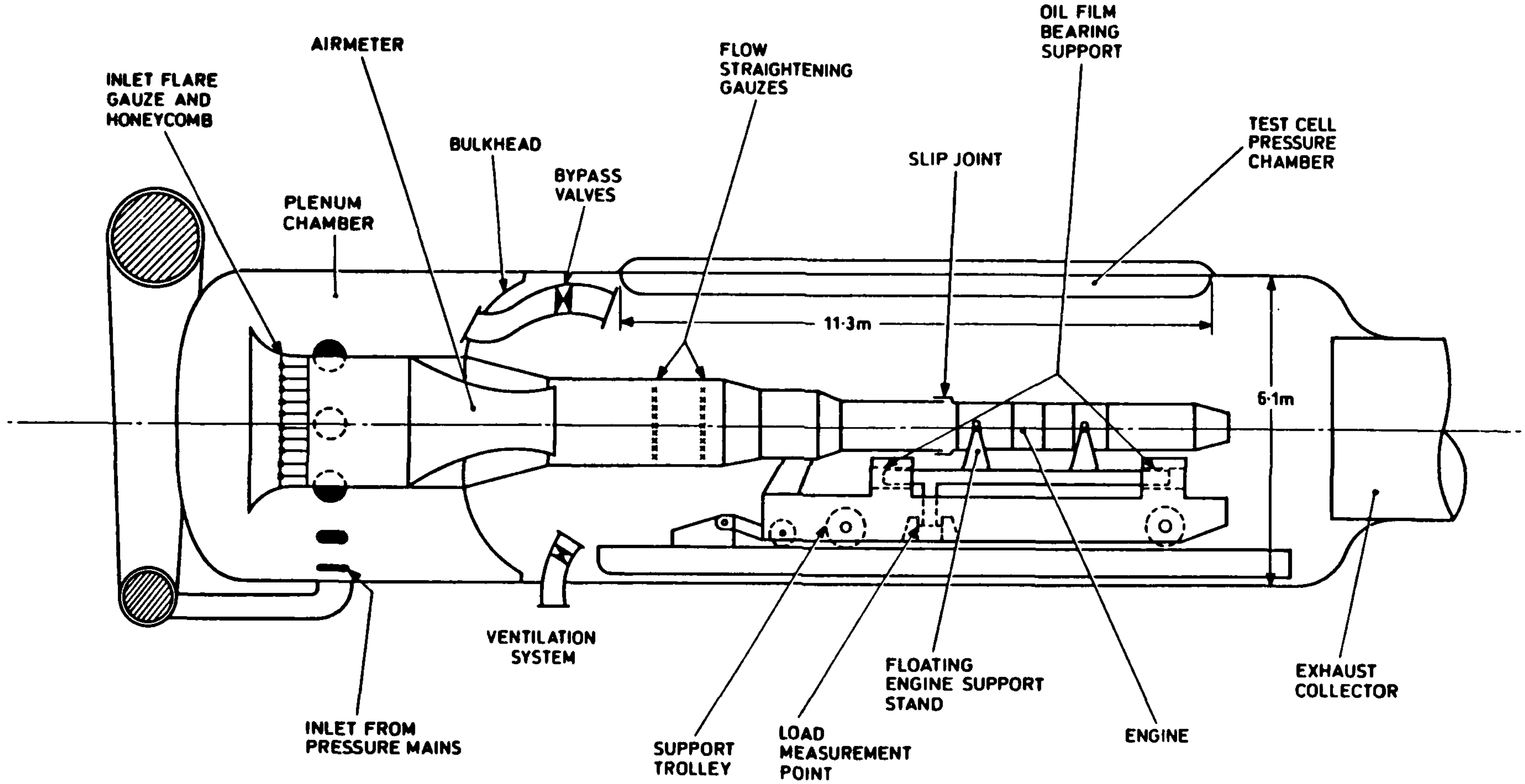

FIG.7 TYPICAL ENGINE INSTALLATION IN RAE (P) ALTITUDE CELL 3

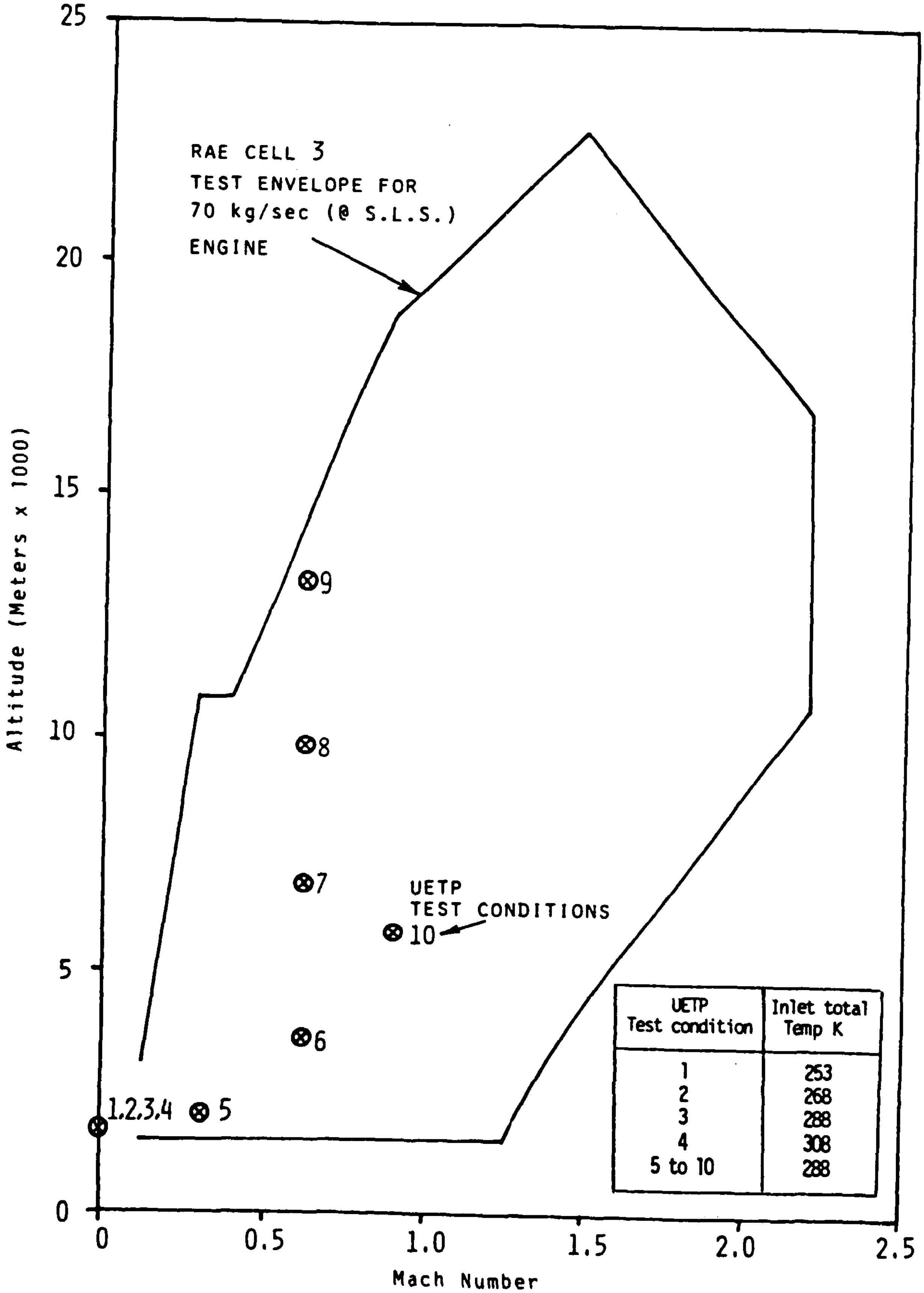

FIG 8 TEST ENVELOPE FOR RAE (P) CELL 3

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17. Abstract

The Uniform Engine Test Programme (UETP) involved the testing of two Pratt and Whitney J57 engines at seven Government-owned test sites in Europe and North America, four of them having altitude test facilities. This collaborative programme was organised by a working group of the Advisory Group for Aerospace Research and Development (AGARD) and provided actual test data as a basis for comparison of methods of testing and analysis amongst the international aero engine testing community. An overview of the UETP is given in this Paper, together with a brief review of the test results. Nozzle coefficients are used as a basis for comparing gross thrust and airflow measurements and differences in some of the other performance parameters are compared with the predicted precision and bias errors.

F5910/1

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